$$\boxed{\gamma} \qquad I(J^{PC}) = 0,1(1^{--})$$

γ MASS

Results prior to 2008 are critiqued in GOLDHABER 10.

The following conversions are useful: 1 eV $= 1.783 \times 10^{-33}$ g $= 1.957 \times 10^{-6}$ m_e; $\lambdabar_C = 1.973 \times 10^{-7}$ m.

VALUE (eV)		CL%	DOCUMENT ID		TECN	COMMENT
< 1	**× 10⁻¹⁸**		[1] RYUTOV	07		MHD of solar wind

• • • We do not use the following data for averages, fits, limits, etc. • • •

VALUE (eV)		CL%	DOCUMENT ID		TECN	COMMENT
			[2] ACCIOLY	10		Anomalous mag. mom.
< 1	× 10⁻²⁶		[3] ADELBERGER	07A		Galactic field existence if Higgs mass
< 1.4	× 10⁻⁷		ACCIOLY	04		Dispersion of GHz radio waves by sun
< 2	× 10⁻¹⁶		FULLEKRUG	04		Speed of 5-50 Hz radiation in atmosphere
< 7	× 10⁻¹⁹		[4] LUO	03		Modulation torsion balance
< 1	× 10⁻¹⁷		[5] LAKES	98		Torque on toroid balance
< 6	× 10⁻¹⁷		[6] RYUTOV	97		MHD of solar wind
< 9	× 10⁻¹⁶	90	[7] FISCHBACH	94		Earth magnetic field
<(4.73±0.45)	× 10⁻¹²		[8] CHERNIKOV	92	SQID	Ampere-law null test
<(9.0 ±8.1)	× 10⁻¹⁰		[9] RYAN	85		Coulomb-law null test
< 3	× 10⁻²⁷		[10] CHIBISOV	76		Galactic magnetic field
< 6	× 10⁻¹⁶	99.7	DAVIS	75		Jupiter magnetic field
< 7.3	× 10⁻¹⁶		HOLLWEG	74		Alfven waves
< 6	× 10⁻¹⁷		[11] FRANKEN	71		Low freq. res. cir.
< 1	× 10⁻¹⁴		WILLIAMS	71	CNTR	Tests Gauss law
< 2.3	× 10⁻¹⁵		GOLDHABER	68		Satellite data
< 6	× 10⁻¹⁵		[11] PATEL	65		Satellite data
< 6	× 10⁻¹⁵		GINTSBURG	64		Satellite data

Column note for RYAN 85 row: OCCUR=2

[1] RYUTOV 07 extends the method of RYUTOV 97 to the radius of Pluto's orbit.

[2] ACCIOLY 10 limits come from possible alterations of anomalous magnetic moment of electron and gravitational deflection of electromagnetic radiation. Reported limits are not "claimed" by the authors and in any case are not competitive.

[3] When trying to measure m one must distinguish between measurements performed on large and small scales. If the photon acquires mass by the Higgs mechanism, the large-scale behavior of the photon might be effectively Maxwellian. If, on the other hand, one postulates the Proca regime for all scales, the very existence of the galactic field implies $m < 10^{-26}$ eV, as correctly calculated by YAMAGUCHI 59 and CHIBISOV 76.

[4] LUO 03 determine a limit on $\mu^2 A < 1.1 \times 10^{-11}$ T m/m^2 (with μ^{-1}=characteristic length for photon mass; A=ambient vector potential) — similar to the LAKES 98 technique. Unlike LAKES 98 who used static, the authors used dynamic torsion balance. Assuming A to be 10^{12} T m, they obtain $\mu < 1.2 \times 10^{-51}$ g, equivalent to 6.7×10^{-19} eV. The rotating modified Cavendish balance removes dependence on the direction of A. GOLDHABER 03 argue that because plasma current effects are neglected, the LUO 03 limit does not provide the best available limit on $\mu^2 A$ nor a reliable limit at all on μ. The reason is that the A associated with cluster magnetic fields could become arbitrarily small in plasma voids, whose existence would be compatible with present knowledge. LUO 03B reply that fields of distant clusters are not accurately mapped, but assert that a zero A is unlikely given what we know about the magnetic field in our galaxy.

[5] LAKES 98 reports limits on torque on a toroid Cavendish balance, obtaining a limit on $\mu^2 A < 2 \times 10^{-9}$ Tm/m^2 via the Maxwell-Proca equations, where μ^{-1} is the characteristic length associated with the photon mass and A is the ambient vector potential in the Lorentz gauge. Assuming $A \approx 1 \times 10^{12}$ Tm due to cluster fields he obtains $\mu^{-1} > 2 \times 10^{10}$ m, corresponding to $\mu < 1 \times 10^{-17}$ eV. A more conservative limit, using $A \approx (1 \ \mu G) \times (600 \ pc)$ based on the galactic field, is $\mu^{-1} > 1 \times 10^9$ m or $\mu < 2 \times 10^{-16}$ eV.

[6] RYUTOV 97 uses a magnetohydrodynamics argument concerning survival of the Sun's field to the radius of the Earth's orbit. "To reconcile observations to theory, one has to reduce [the photon mass] by approximately an order of magnitude compared with" DAVIS 75.

[7] FISCHBACH 94 report $< 8 \times 10^{-16}$ with unknown CL. We report Bayesian CL used elsewhere in these Listings and described in the Statistics section.

[8] CHERNIKOV 92 measures the photon mass at 1.24 K, following a theoretical suggestion that electromagnetic gauge invariance might break down at some low critical temperature. See the erratum for a correction, included here, to the published result.

NODE=S000M;LINKAGE=RU
NODE=S000M;LINKAGE=AC

NODE=S000M;LINKAGE=AD

NODE=S000M;LINKAGE=LU

NODE=S000M;LINKAGE=E

NODE=S000M;LINKAGE=RY

NODE=S000M;LINKAGE=C

NODE=S000M;LINKAGE=A

[9] RYAN 85 measures the photon mass at 1.36 K (see the footnote to CHERNIKOV 92).

[10] CHIBISOV 76 depends in critical way on assumptions such as applicability of virial theorem. Some of the arguments given only in unpublished references.

[11] See criticism questioning the validity of these results in GOLDHABER 71, PARK 71 and KROLL 71. See also review GOLDHABER 71B.

NODE=S000M;LINKAGE=B
NODE=S000M;LINKAGE=D
NODE=S000M;LINKAGE=F

γ CHARGE

NODE=S000Q

OKUN 06 has argued that schemes in which all photons are charged are inconsistent. He says that if a neutral photon is also admitted to avoid this problem, then other problems emerge, such as those connected with the emission and absorption of charged photons by charged particles. He concludes that in the absence of a self-consistent phenomenological basis, interpretation of experimental data is at best difficult.

NODE=S000Q

VALUE (e)	CHARGE	DOCUMENT ID		TECN	COMMENT	
<1 $\times 10^{-46}$	mixed	[12] ALTSCHUL	07B	VLBI	Aharonov-Bohm effect	NODE=S000Q
<1 $\times 10^{-35}$	single	[13] CAPRINI	05	CMB	Isotropy constraint	OCCUR=2
• • • We do not use the following data for averages, fits, limits, etc. • • •						
<1 $\times 10^{-32}$	single	[12] ALTSCHUL	07B	VLBI	Aharonov-Bohm effect	
<3 $\times 10^{-33}$	mixed	[14] KOBYCHEV	05	VLBI	Smear as function of $B \cdot E_\gamma$	
<4 $\times 10^{-31}$	single	[14] KOBYCHEV	05	VLBI	Deflection as function of $B \cdot E_\gamma$	OCCUR=2
<8.5 $\times 10^{-17}$		[15] SEMERTZIDIS	03		Laser light deflection in B-field	
<3 $\times 10^{-28}$	single	[16] SIVARAM	95	CMB	For $\Omega_M = 0.3$, $h^2 = 0.5$	
<5 $\times 10^{-30}$		[17] RAFFELT	94	TOF	Pulsar $f_1 - f_2$	
<2 $\times 10^{-28}$		[18] COCCONI	92		VLBA radio telescope resolution	
<2 $\times 10^{-32}$		COCCONI	88	TOF	Pulsar $f_1 - f_2$ TOF	

[12] ALTSCHUL 07B looks for Aharonov-Bohm phase shift in addition to geometric phase shift in radio interference fringes (VSOP mission).

NODE=S000Q;LINKAGE=AL

[13] CAPRINI 05 uses isotropy of the cosmic microwave background to place stringent limits on possible charge asymmetry of the Universe. Charge limits are set on the photon, neutrino, and dark matter particles. Valid if charge asymmetries produced by different particles are not anticorrelated.

NODE=S000Q;LINKAGE=CA

[14] KOBYCHEV 05 considers a variety of observable effects of photon charge for extragalactic compact radio sources. Best limits if source observed through a foreground cluster of galaxies.

NODE=S000Q;LINKAGE=KO

[15] SEMERTZIDIS 03 reports the first laboratory limit on the photon charge in the last 30 years. Straightforward improvements in the apparatus could attain a sensitivity of 10^{-20} e.

NODE=S000Q;LINKAGE=QS

[16] SIVARAM 95 requires that CMB photon charge density not overwhelm gravity. Result scales as $\Omega_M h^2$.

NODE=S000Q;LINKAGE=SI

[17] RAFFELT 94 notes that COCCONI 88 neglects the fact that the time delay due to dispersion by free electrons in the interstellar medium has the same photon energy dependence as that due to bending of a charged photon in the magnetic field. His limit is based on the assumption that the entire observed dispersion is due to photon charge. It is a factor of 200 less stringent than the COCCONI 88 limit.

NODE=S000Q;LINKAGE=B

[18] See COCCONI 92 for less stringent limits in other frequency ranges. Also see RAFFELT 94 note.

NODE=S000Q;LINKAGE=A

γ REFERENCES

NODE=S000

ACCIOLY	10	PR D82 065026	A. Accioly, J. Helayel-Neto, E. Scatena	(LABEX+)	REFID=53482
GOLDHABER	10	RMP 82 939	A.F. Goldhaber, M.M. Nieto	(STON, LANL)	REFID=53297
ADELBERGER	07A	PRL 98 010402	E. Adelberger, G. Dvali, A. Gruzinov	(WASH, NYU)	REFID=52247
ALTSCHUL	07B	PRL 98 261801	B. Altschul	(IND)	REFID=51815
Also		ASP 29 290	B. Altschul	(SCUC)	REFID=52312
RYUTOV	07	PPCF 49 B429	D.D. Ryutov	(LLNL)	REFID=52248
OKUN	06	APP B37 565	L.B. Okun	(ITEP)	REFID=52693
CAPRINI	05	JCAP 0502 006	C. Caprini, P.G. Ferreira	(GEVA, OXFTP)	REFID=52696
KOBYCHEV	05	AL 31 147	V.V. Kobychev, S.B. Popov	(KIEV, PADO)	REFID=52697
ACCIOLY	04	PR D69 107501	A. Accioly, R. Paszko		REFID=50003
FULLEKRUG	04	PRL 93 043901	M. Fullekrug		REFID=52249
GOLDHABER	03	PRL 91 149101	A.S. Goldhaber, M.M. Nieto		REFID=49543
LUO	03	PRL 90 081801	J. Luo et al.		REFID=49353
LUO	03B	PRL 91 149102	J. Luo et al.		REFID=49544
SEMERTZIDIS	03	PR D67 017701	Y.K. Semertzidis, G.T. Danby, D.M. Lazarus		REFID=49265
LAKES	98	PRL 80 1826	R. Lakes	(WISC)	REFID=45913
RYUTOV	97	PPCF 39 A73	D.D. Ryutov	(LLNL)	REFID=49487
SIVARAM	95	AJP 63 473	C. Sivaram	(BANG)	REFID=52695
FISCHBACH	94	PRL 73 514	E. Fischbach et al.	(PURD, JHU+)	REFID=43879
RAFFELT	94	PR D50 7729	G. Raffelt	(MPIM)	REFID=44063
CHERNIKOV	92	PRL 68 3383	M.A. Chernikov et al.	(ETH)	REFID=42032
Also		PRL 69 2999 (erratum)	M.A. Chernikov et al.	(ETH)	REFID=43763
COCCONI	92	AJP 60 750	G. Cocconi	(CERN)	REFID=42098
COCCONI	88	PL B206 705	G. Cocconi	(CERN)	REFID=40642
RYAN	85	PR D32 802	J.J. Ryan, F. Accetta, R.H. Austin	(PRIN)	REFID=10010
CHIBISOV	76	SPU 19 624	G.V. Chibisov	(LEBD)	REFID=10009
		Translated from UFN 119 551.			

DAVIS	75	PRL 35 1402	L. Davis, A.S. Goldhaber, M.M. Nieto	(CIT, STON+)	REFID=10008
HOLLWEG	74	PRL 32 961	J.V. Hollweg	(NCAR)	REFID=10007
FRANKEN	71	PRL 26 115	P.A. Franken, G.W. Ampulski	(MICH)	REFID=10004
GOLDHABER	71	PRL 26 1390	A.S. Goldhaber, M.M. Nieto	(STON, BOHR, UCSB)	REFID=49736
GOLDHABER	71B	RMP 43 277	A.S. Goldhaber, M.M. Nieto	(STON, BOHR, UCSB)	REFID=10011
KROLL	71	PRL 26 1395	N.M. Kroll	(SLAC)	REFID=10012
PARK	71	PRL 26 1393	D. Park, E.R. Williams	(WILC)	REFID=49737
WILLIAMS	71	PRL 26 721	E.R. Williams, J.E. Faller, H.A. Hill	(WESL)	REFID=10005
GOLDHABER	68	PRL 21 567	A.S. Goldhaber, M.M. Nieto	(STON)	REFID=10003
PATEL	65	PL 14 105	V.L. Patel	(DUKE)	REFID=10002
GINTSBURG	64	Sov. Astr. AJ7 536	M.A. Gintsburg	(ASCI)	REFID=10001
YAMAGUCHI	59	PTPS 11 37	Y. Yamaguchi		REFID=52250